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Sven Klimpel
Thomas Kuhn
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Biodiversity and Evolution of Parasitic Life in the Southern Ocean

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Preface

Antarctica is the most Southern continent on earth and had millions of years time to adapt its environments from tropical ones of the giant continent *Gondwana* to most cold ones in our times. This led to an enormous reduction of species and for the survivors strict specialization and adaption to the new environment was needed. Parasites, which lived in or on these animals (migrating with their continents), had the same problems like their hosts. They had to adapt their life cycles and their body properties to the new conditions.

This book reports from the sometimes sophisticated adaptions of some of these survivors of the struggle for life in and around Antarctica.

Düsseldorf, Germany Heinz Mehlhorn

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Düsseldorf, Frankfurt a.M., August 2016
Sven Klimpel
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Sven Klimpel studied Biology at the Christian-Albrechts-University Kiel/IfM-Geomar (now Helmholtz Centre for Ocean Research) and then completed his doctorate and his habilitation at the Institute of Zoomorphology, Cell Biology and Parasitology of the Heinrich-Heine-University Düsseldorf. Since 2010 he is full professor and head of the department "Integrative Parasitology and Zoophysiology (IPZ)" of the Goethe-University Frankfurt am Main in cooperation with the Senckenberg Biodiversity and Climate Research Centre/Senckenberg Society for Nature Research and the director of the Institute for Ecology, Evolution and Diversity. His primary research interests are the ecology, evolution, life-cycle strategies and host-parasite co-evolution of aquatic and terrestrial protozoan/metazoan parasites, pathogens and their invertebrate/vertebrate intermediate hosts and vectors. In his laboratory, he and his coworkers combine traditional morphological methods with up-to-date molecular techniques. He participates in numerous scientific research cruises, including some to the Southern Ocean (Antarctica).

Thomas Kuhn studied biology at the Heinrich-Heine-University (HHU) Düsseldorf, majoring in parasitology, zoology, and genetics. In 2013, he obtained his doctorate at the Institute for Ecology, Evolution and Diversity of the Goethe-University and the Biodiversity and Climate Research Centre (BiK-F) in Frankfurt/Main, Germany. Since 2013, he works as a junior research group leader (Molecular and Aquatic Parasitology) at the department "Integrative Parasitology and Zoophysiology" at the Goethe-University, Frankfurt/Main, Germany. His research aims to understand the complex interrelationships between aquatic metazoan pathogens and their respective vertebrate and invertebrate hosts. He is particularly interested in the morphological and molecular identification, (co-)evolution and ecology as well as the zoogeography of aquatic, zoonotic parasites and their implications on food safety.

Heinz Mehlhorn, Düsseldorf, Germany. He has investigated the transmission pathways of human and animal parasites for over 40 years at German and international universities and he and his university spin-off company Alpha-Biocare have developed many antiparasitic medical products based on more than 20 patents – several in cooperation with big international companies. He is editor and author of the Springer *Encyclopedia of Parasitology* and has published 25 books, more than 250 original papers, and has served as Managing Editor of the journal *Parasitology Research* since 1981. A long list of renown international scientists did their PhD work in his laboratory and remain still today interconnected as a large group of lovers of parasitology.

Chapter 1
Introduction: Biodiversity and Evolution of Parasitic Life in the Southern Ocean

Sven Klimpel, Thomas Kuhn, and Heinz Mehlhorn

Researchers of various disciplines, including taxonomy, ecology, and physiology, have long been attracted to the Southern Ocean environment that lies at the limits of the physical conditions capable of supporting life and thus constitutes an exceptional ecosystem for undertaking fundamental research on the relationship between the climate and evolutionary processes (Clarke et al. 2007a and ref. therein; Ducklow et al. 2007). The establishment of the Antarctic Circumpolar Current (ACC) and its associated oceanographic regime in the Early Cenozoic fostered unique adaptations of both, marine and terrestrial organisms, relatively unaffected by biotic exchange (Clarke et al. 2007a). Low air and water temperatures, lack of coastal zones due to a thick shelf-ice cover, and drifting and stranding of icebergs are only some of those unique environmental features that necessitate special adaptations of terrestrial and marine floral and faunal species to extreme environmental conditions (Klimpel et al. 2010). A particular characteristic in the marine environment is the missing of a strict separation between the continental shelf and the deep-sea, enabling deep-sea species to occur also in shallower waters and especially benthodemersal shallow water species to extend their range into the deep-sea (Klimpel et al. 2010).

To date, many endemic species have been recorded from Antarctica, illustrating the unique history and environment of the region. However, dramatic climatic

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changes have caused major shifts in the species composition (e.g., Clarke and Crame 1992; Clarke et al. 2007a, b). Recent climate change and rising temperatures will likely intensify this effect on the endemic biota in the high Antarctic and Southern Ocean, possibly leading to another shift in species composition and distribution in the future.

The Antarctic Peninsula with its surrounding islands (e.g., Elephant and King George Island, both South Shetlands), for example, is one of those areas on the globe which is currently experiencing rapid regional climatic changes, with more than 1.5 °C rise in mean annual temperature since 1950 (compared with a global mean increase of appr. 0.6 °C) (e.g., Clarke et al. 2007a; Vaughan et al. 2003). The loss of seven larger ice fields during the past 60 years, including the collapse of the Wordie Ice Shelf in the 1980s and the middle section of the Larsen Ice Shelf (Larsen B) in 2002 are only the most evident consequences of climatic impacts on the local environment (Vaughan and Doake 1996; Doake and Vaughan 1991; Clarke et al. 2007a; Domack et al. 2005).

Krill, cephalopods, and Antarctic fish species are considered the key species of the Antarctic marine food web (e.g., Loeb et al. 1997). The fish species composition, biomass, zoogeographical distribution, feeding ecology, and reproduction are comparatively well known (e.g., Kock 1992; Kock and Stransky 2000; Flores et al. 2004; Bushula et al. 2005; Eastman 2005; Kock 2005a, b). With currently 283 recognized species, it is generally dominated by the perciform suborder Notothenioidei (Kock 2005a, b; Froese and Pauly 2016), which comprises the majority of species in shelf waters down to 500 m water depth (Flores et al. 2004; Kock and Stransky 2000).

Being a species-rich but often well-hidden component of the Southern Ocean fauna, fish parasites have been studied by various research groups. Earlier works focused on new species descriptions and the faunistic description, especially of parasitic helminths (e.g., Digenea: Zdzitowiecki 1991a, 1996, 1997; Laskowski et al. (2014); Cestoda: Rocka and Zdzitowiecki 1998; Wojciechowska 1991; Wojciechowska et al. 1994; Nematoda: Klöser et al. 1992; Palm et al. 1994, 1998; Acanthocephala: Zdzitowiecki 1990, 1991b, 1996). Most research activities have been carried out on Antarctic notothenioids and also channichtyids from shallow coastal waters or the open sea shelf (e.g., Zdzitowiecki 1991a, 1997; Santoro et al. 2014), where species are easy to catch and, therefore, more available for such studies. Investigations along the Antarctic continental slope and the deep-sea are limited (e.g., Walter et al. 2002). Most parasitological studies from the Southern Ocean, especially from the Antarctic Peninsula and the eastern Weddell-Sea, revealed a species-rich fish parasite fauna, including mainly endemic and noncosmopolitan species (e.g., Palm et al. 1998; Zdzitowiecki and Laskowski 2004; Brickle et al. 2005; Rocka 2006).

Other examples of fish parasitological investigations were published mainly by scientists such as Rocka (Rocka 2002, 2003, 2004); Rocka and Zdzitowiecki (1998); Wojciechowska (1991); Wojciechowska et al. (1994); Zdzitowiecki (1990, 1991b, 1996); Zdzitowiecki and Laskowski (2004) and Zdzitowiecki and Pisano (1996). Rocka (2006) summarized the available information about the life cycle biology, specificity, and geographical distribution of the parasitic helminth groups Digenea, Cestoda, Nematoda, and Acanthocephala of Antarctic bony fishes and elasmobranchs. The author stated that almost all of the helminth species maturing in Antarctic bony fishes are endemic, whereas only extremely few parasite species are cosmopolitan or bipolar. Specificity to the intermediate or paratenic hosts of the majority of Antarctic helminths is low, whereas that for the definitive host is often higher (Rocka 2006).

During first investigations on the life cycle biology and the zoogeography of, e.g., anisakid nematodes in the Weddell Sea and around the South Shetland Islands, different benthic and pelagic life cycles could be identified for the anisakid nematodes *Contracaecum radiatum*, *C. osculatum* (e.g., Klöser et al. 1992; Klöser and Plötz 1992)), *Pseudoterranova decipiens* (e.g., Palm et al. 1994; Palm 1999), and specimens of the genus *Anisakis* (e.g., Klimpel et al. 2010; Kuhn et al. 2011)) (Fig. 1.1). Although these anisakids have explored the extreme Antarctic environment, they have maintained the principal life cycle biology that is known for their relatives from non-Antarctic waters such as in the North Atlantic.

Generally, the biodiversity of fish parasites in benthodemersal fish from shallow waters and from deep water fish is species rich, but demonstrates low host specificity for most of the collected species (Palm et al. 1998, 2007; Walter et al. 2002;

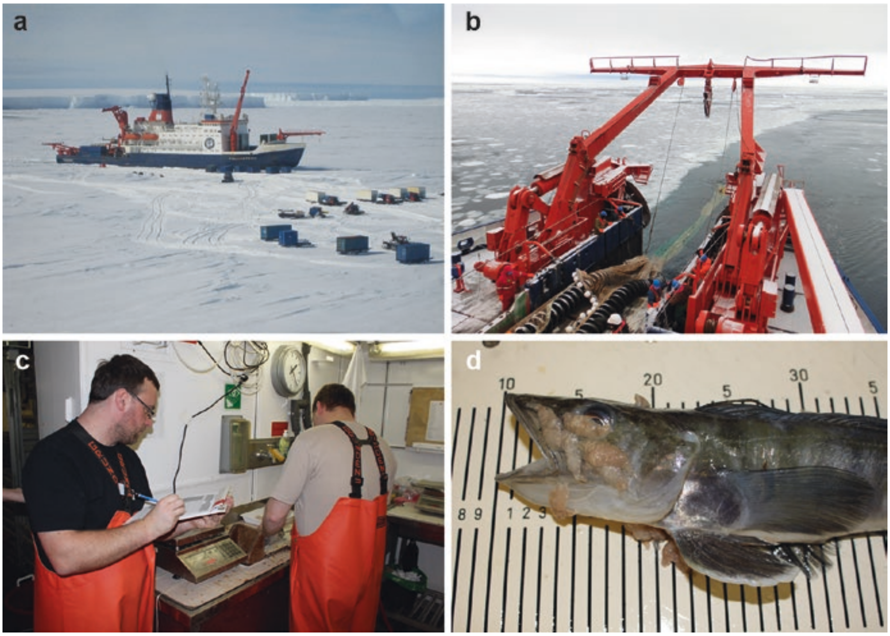

Fig. 1.1 Research vessel (*RV*) and scientific equipment (**a**, **b**), scientific investigation of Antarctic fish material, and typical ectoparasites (**c**, **d**). (**a**) *Polarstern* during the research cruise ANT XXIII/8. The research vessel *Polarstern* is the most important tool for German polar research. (**b**) Fish trawl from the waters around Elephant Island. (**c**) Scientist during data collection in the wet lab of the RV *Polarstern*. (**d**) Mackerel icefish *Champsocephalus gunnari*, Channichthyidae) with parasitic leeches

Klimpel et al. 2009). Mammalian parasites, for example, seem to use mainly the nototheniids and channichthyids as common transmission routes into their seal final hosts; however, some have also explored parallel host systems that utilize different combinations of final and intermediate hosts (e.g., Palm et al. 2007). Until now, comparative investigations that could indicate long-term changes in the parasite fauna are still missing, and many, often more rare fish species, have not or only sporadically been examined. The present monograph should cover some of the still missing aspects on fish parasitological research in Antarctic waters.

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Chapter 2
Antarctica: The Peculiar World

Birgit Mehlhorn and Heinz Mehlhorn

The continent Antarctica, which was officially discovered in the year 1820, obtained its name from the Greek term *antarktikos* = being situated opposite to the arctic, which comprises the Northern ice region on the globe. The Antarctica of our days represents a land area of about 13–14 million square kilometers being covered by very thick ice layers (up to 4700 m), which laterally overlap often considerably for many miles the icy waters around this fifth continent. This antarctical ice represents around 80–90 % of the ice on earth (= respectively about 70 % of the freshwater). The land mass of this continent includes numerous large lakes (up to 2500 m deep), which are all covered by this enormous ice shield. However, besides its outer icy aspect Antarctica includes a belt of active volcanos, which stretches over the continent from Victorialand to the Antarctic peninsula. The biggest volcano is the 3800 m high Mount Erebus on Ross Island.

The development of the continent Antarctica has a long history. Its oldest regions (e.g., Enderbyland) contains material that has an age of 3 billion years. About 170 million years ago Antarctica was a part of the large continent *Gondwana*. This region of earth was free of ice and gave room to fruitful soil, plants and a rich spectrum of animals including dinosaurs as is proven by the finding of their fossils dated 145–100 million years before our times.

During the period of the late Jura period, the supercontinent Gondwana started to become divided into precursors of the continents of our times and a land mass comprising Antarctica/Australia. Both were later separated from each other. Since this separation proceeded very slowly, animals and plants had sufficient time to become adapted at the changing temperatures and/or to develop sophisticated survival strategies in changing climates. Thus the species living today on the continent and in the surroundings of Antarctica are completely different from those at the beginning of

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the continental drift. However, although the recent living conditions seem bad with respect to human needs, the fauna in the sea and around Antarctica is extremely large, but is in many aspects not yet really known.

Animals like seals, fishes, crustaceans, penguins, whales etc. within the water or birds with regular short contacts to the water had time enough during the continental shift to adapt their body needs to the high salinity of the ocean in Antarctica, where 35 per mille salt contents in the sea water are reached in contrast to only 3–5 per mille salt measured in the ice. However, the high saline content decreases the freezing point of the Antarctic sea water to –1.9 degrees Celsius. This temperature is "rather warm" compared to Antarctic air temperatures of –40 °C, which often occur and have to become survived e.g., by penguins.

The fauna in the sea around Antarctica is very rich and shows many sophisticated adaptations to peculiar conditions. Giant masses of typical Antarctic crustaceans (krill, *Euphausia superba*, Fig. 2.1) and related species are the basic food of fishes (~200 species) and whales (Fig. 2.2), which spend their time there in the Antarctic summer and ingest in addition to the krill also giant amounts (~50 million tons) of cephalopods (= squids). Penguins (Fig. 2.3) and seals breed on shore and feed fish, which are attacked by squads of ecto- and endoparasites like copepods of the families Ergasilidae and Lernaeidae. The latter appear worm-like and penetrate from outside with their anchor-like anterior ends into the body cavity of fishes. They can be easily recognized by their two egg-sacks, which may reach often a length of 4–5 cm (Figs. 2.4 and 2.5).

All these animals belonging to practically all tribes of the animal phylum had developed their skills to survive in about 40–45 million years, when the first ice development started reaching a full coverage about 3 million years ago. Humans would not have the chance to survive under the present conditions, if they would not be transported by ice-breaking ships and wear warm-holding suits (Figs. 2.6, 2.7, and 2.8).

Thus the authors of the present book want to report on the adaptations of several Antarctic parasites, which have learnt to escape the attacks of their hosts and had become able to survive the extreme low temperatures in their icy biotopes (Tables 2.1 and 2.2).

Fig. 2.1 Macrophoto of an adult crustacean (*Euphausia superba*) belonging to the so-called krill

Fig. 2.2 Photo of a jumping humpback whale, which are not shy and come close to boats. They stay in Antarctica in summer, but in winter in the Australian and South American sea, where they give birth to their progeny

Fig. 2.3 Two gentoo penguins (*Pygoscelis papua*) at the Antarctic shore close to the German Dallmann summer station

Fig. 2.4 Macrophoto of the surface of an Antarctic fish with an attached female lernaeid copepod (Crustacea). Note the two very long egg sacks

Fig. 2.5 Macrophoto of the opened inner side of the same fish depicted in Fig. 2.4 showing the deep anchoring system of the copepod's anterior end

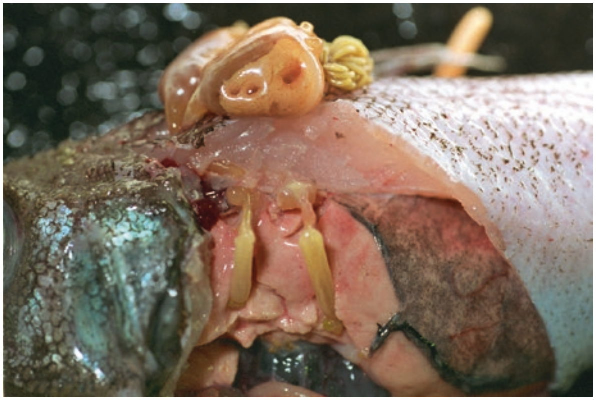

Fig. 2.6 Photo of the German research vessel *Polarstern* (Polar star) during the "Century Antarctic Expedition" in February until April of the year 2000. It was photographed during a helicopter flight to the German All-Year research station Neumayer showing also the high borders of the shelf ice